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ABSTRACT

This investigation addressed the following questions: (1) Can the ability to control variables be taught to high school biology students who, on a written test of logical operations, do not demonstrate formal reasoning; (2) Would students who are classified as early formal operational thinkers on the written test of logical operations be able to benefit more from the training than students who are classified as early or late concrete operational thinkers; and (3) If the ability to control variables can be learned, is it generalizable to problems utilizing novel materials? Sixty-five high school students (29 males and 36 females) enrolled in a biology course at Delphi High School in Delphi, Indiana, served as subjects. This research found that training was not successful in promoting appreciable understanding of the controlling variables concept. Also found was that understanding of the concept of controlling variables is lacking and not easily corrected. The training of specific Piagetian concepts was successful, but the students did not exhibit transfer of the training. (Author/DS)

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TRAINING EFFECTS AND GENERALIZATION OF THE ABILITY TO CONTROL VARIABLES IN HIGH SCHOOL BIOLOGY STUDENTS

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Introduction

According to the Piagetian model of intellectual development, recognition of the necessity for controls when testing hypotheses requires formal reasoning ability.[1] Further, the ability to perform controlled experiments allegedly arises as a consequence of a general development of formal reasoning abilities and cannot be directly taught to students who are not already in the formal operational stage or on the threshold of that stage.*

Since the ability to perform controlled experiments comprises an important component of all high school science curricula, and since numerous investigations suggest that as much as 50 percent of high school students and adults fail to acquire formal reasoning abilities,[4-8] Piaget's position with regard to the nature of acquisition of this ability should be tested.

Problem Statement

This investigation addressed itself to the following questions. (1) Can the ability to control variables be taught to high school biology students who on a written test of logical operations, do not demonstrate formal reasoning? (2) Are students who are classified as early formal operational thinkers on

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*In a recent interview Piaget was asked: "What if the teacher were to demonstrate the experiment (i.e., the verification method) to the class?" and he replied, "It would be completely useless. The child must discover the method for himself."[2] For a more complete discussion of Piaget's conceptions of development and learning, see Piaget, 1964.[3]

the written test of logical operations able to benefit more from the training than students who are classified as early or late concrete operational thinkers? (3) If the ability to control variables can be learned, is it generalizable to problems utilizing novel materials?

Since the subjects involved in the present study were high school students and all were over 14 years of age, it was hypothesized that level of physical maturation would not be a factor preventing acquisition of the desired ability.*

Related Research

Numerous attempts have been made to train children on the Piagetian conservation concepts. These studies have been extensively reviewed by Brainerd and Allen[11] and Beilin[12] so they will not be detailed here. In brief the reviews show that in almost all cases training of specific conservations has been successful. However, this training is not transferable to the conservation of non-trained quantities. These results are taken to be more supportive of Piagetian predictions than not.

Far fewer training attempts have been made with the formal reasoning tasks. Case[13] was successful in training intelligent field-independent 7-8-year-old children to control variables by using a number of concrete examples. He argued, however, that the children responded successfully on the posttest tasks using concrete operational thought processes and had not acquired formal reasoning abilities. Bredderman[14] attempted to train

*Piaget states that formal operational thought for normal adolescents begins to develop at around 11-12 years of age and reaches an equilibrium state at around 14-15 years of age. Epstein[9, 10] has discovered spurts of brain growth at ages 2-4, 6-8, 10-12, and 14-16. These growth spurts correspond remarkably well with the transitional periods between Piaget's stages.

two groups of 10-13-year-old children to control variables. One group received training relying upon external reinforcement and the second group received training designed to induce internal cognitive conflict. Both trained groups showed only slightly more improvement than the control group on the posttest. Further, on a retention test given one month later, all three groups had almost identical scores. Bass and Montague[15] trained 14-15-year-old physical science students on Inhelder and Piaget's balance beam and inclined plane problem. They found significant improvement of student performance on posttests. However, most students improved no more than one substage from pre- to posttesting. Case and Fry[16] instructed a group of 15 low socio-economic level 14-year-olds, who had not reached Piaget's stage of formal operations, to design controlled experiments. On a nonstandardized written posttest the experimental group performed significantly better than a matched control group.

Method

Subjects

Sixty-five high school students (29 males and 36 females) enrolled in a second semester biology course at Delphi High School in Delphi, Indiana served as subjects. The subjects ranged in age from 14 years, 7 months to 17 years, 10 months with a mean age of 15 years, 5 months. Delphi High School is a modern school with over 800 students located in a rural section of North Central Indiana. The principal occupation of the residents is farming.

Procedure

The experimental design employed in this investigation is referred to

by Campbell and Stanley[17] as the posttest-only design. Students from four biology classes were randomly divided into two groups--33 students received training on the ability to control variables and 32 students received no training. The training involved materials identical to those used by Inhelder and Piaget in their exclusion of irrelevant variables task.[1] Timing devices were also included. This task tests a subject's ability to control variables using a simple pendulum. Training also involved materials obtained from the Science Curriculum Improvement Study's Energy Sources unit.[18] These materials, called "rotoplanes," provided subjects with additional experiences requiring the control of variables.

Following the training phase, both experimental and control group subjects were posttested using three Piagetian tasks:[1] exclusion of irrelevant variables (the pendulum task), separation of variables (bending rods), and equilibrium in the balance. Use of the exclusion task allowed determination of the effectiveness of the training in facilitating the ability to control variables with materials identical to the training materials (specific transfer). The separation of variables task was used to determine whether or not the training was generalizable to a problem also involving the control of variables but using novel materials (non-specific transfer). The equilibrium in the balance task was also used to determine the extent to which the training was generalizable. This task does not involve controlling variables, rather it involves proportional reasoning. Piaget claims, however, that this reasoning ability develops concomitantly with the ability to control variables.

Prior to the training phase both experimental and control group students were administered a pencil and paper test of logical operations developed by Longeot[19,20] which allowed classification of the students into concrete, transitional, and formal operational stages of development. This was done to enable us to determine if the effectiveness of the training was related to level of intellectual development of the student.

Treatment

The experimental group was subdivided into two groups. Each group participated in four training sessions of 50 minutes each. Two experimenters participated as instructors in each of the training sessions. Subjects worked in teams of two at tables upon which the experimental materials had been distributed. Each training session involved concrete experiments requiring identification and control of variables for successful completion. The basic procedure employed in the training sessions followed the SCIS exploration-invention-discovery sequence and mode of instruction. This instructional sequence and mode was designed to be compatible with Piaget's equilibration model of intellectual development.[21,22]

Tasks used during the four training sessions presented subjects with two major problems involving the control of variables. The first problem required the determination of the period of a pendulum. The variables which had to be identified and controlled for correct solution were length of string, angle of drop, weight of bob, and amount of push given the bob. The second problem involved the rotoplanes. Subjects were given an initial problem of determining

what variables affected the number of times the rotoplane platform would spin around before it came to a stop. Possible variables included the number of propellers used, the number of rubber bands used, the number of twists in the rubber bands, the position of the propellers, and the angle at which the rotoplane platform was placed. Following identification of these variables and others, the subjects were presented the problem of determining the effect that the number of twists in the rubber band had on the number of rotations of the platform.

During the first training session, the subjects were given an opportunity for exploration into the pendulum materials and problem. The concepts of period of the pendulum and variables were introduced (invented) during the second training session. The word period was introduced to refer to the length of time it takes the bob to make one complete swing. The word variable was introduced by having the students list all the factors which they thought might affect the period on the chalkboard. The students were then told that each of the factors was called a variable. Following introduction of these terms, subjects were provided opportunity to test which variables did or did not affect the period. During the third training session, the concept of a controlled experiment was introduced (invented) in relation to the identified variables in the pendulum problem. This was done by first pointing out that the only way to arrive at an unambiguous test of the effect of a single variable was to change that variable while keeping the others the same. This process was discussed at length with respect to each of the variables. Subjects were then allowed further opportunity to measure the period of the pendulum assuring that all variables except the one being tested were kept the same. The fourth session involved experiments in which the concepts of variables and controlled variables were

applied to problems with novel materials, i.e., the rotoplanes. This activity is part of the "discovery" phase of the SCIS learning sequence.

Posttests

The three Piagetian tasks and the scoring procedures employed during the posttest phase have been described in detail elsewhere,[23] therefore they will not be discussed at length here. It suffices to indicate that subjects were interviewed individually on the three tasks. Scores were awarded on the basis of the quality of subjects' verbal responses and their ability to exhibit appropriate behaviors, i.e., to control variables on the exclusion, and separation of variables tasks, and to hang weights in correct locations on the equilibrium task. Task responses were categorized and points awarded as follows:

IIA.	Early concrete operational - one point
IIB.	Fully concrete operational - two points
IIIA.	Early formal operational - three points
IIIB.	Fully formal operational - four points

The Tasks

Exclusion of irrelevant variables. This task tested the subjects's ability to control and exclude irrelevant variables, using a simple pendulum. First the examiner pointed out the independent and dependent variables. The subject was then given the problem of determining what variables affect the period. Since the only causal factor was the length of the string, the factors of weight of bob, angle of drop, and force or push must be excluded. This demonstration required understanding of the concept "all other things being equal."

Separation of variables. This task tested the subject's ability to identify and control variables. Given six flexible rods of varying length, diameter, shape, and material and hanging weights, the subject was asked to identify variables

and demonstrate proof of the effect of each variable on the amount of bending of the rods.

Equilibrium in the balance. Using a balance beam and hanging weights, this task tested the subject's ability to balance various combinations of weights at various locations along the beam, e.g., given a 10 unit weight 5 units of length from the fulcrum, the examinee was asked to predict the proper location of a 5 unit weight to achieve a balance. Successful completion of this task implied understanding of inverse proportion.

Results

The Longeot test of logical operations was administered to subjects in both the experimental and control groups. This was done to avoid differential treatment of the two groups prior to the training phase. Subject responses on the examination were classified as follows:

14%	Early concrete operational-IIA
41%	Fully concrete operational-IIB
35%	Early formal operational-IIIA
8%	Fully formal operational-IIIB

The mean score of the experimental group was 15.2 and mean score of the control group was 14.9. These mean scores did not differ significantly at the .05 level ($t = .48$; $p < .30$). These percentages are very similar to the percentages obtained by Lawson[24] who classified a sample of high school biology students from Oklahoma into Piagetian stages using a battery of four Piagetian tasks. In that sample Lawson found 18% of the students concrete-IIA, 47% concrete-IIB, 33% formal-IIIA, and 2% formal-IIIB. This close correspondence in percentages of students classified at each of the four developmental levels is striking in that the two samples were drawn from different parts of the country and different instruments were used to categorize students.

Table 1 shows the mean posttest scores for the experimental and control groups on the three Piagetian tasks. The experimental group's mean score on the exclusion task (the trained task) of 3.12 was significantly greater than on the control group's mean score of 2.53 ($t = 2.74$; $p < .01$). On the separation of variables task the experimental group's mean score of 2.57 was not significantly different from the control group's mean score of 2.56 ($t = .09$; $p = .93$). The mean scores on the equilibrium task of 2.57 and 2.69 for the respective groups were also not significantly different ($t = -.72$; $p = .47$).

Insert Table 1

about here

One of the two subjects classified at the concrete operational-IIA level on the Longeot test was classified at the concrete operational-IIB level on the exclusion task (a gain of one substage following training) and the other subject was classified at the formal operational-IIIA level on the exclusion task (a gain of two substages). Thirteen experimental group subjects were classified as concrete-IIB thinkers on the Longeot test. Of those 13, three scored at the formal-IIIA level on the exclusion task (+1 substage) and three scored at the formal-IIIB level on the exclusion task (+2 substages). The remaining seven subjects were classified at the concrete-IIB level (+0 substages). Of the 9 experimental group subjects classified as formal-IIIA thinkers on the Longeot test, four were classified at formal-IIIA level on the exclusion task (+0 substage), four scored at the formal-IIIB level on the exclusion task (+1 substage), and one subject was classified at the concrete-IIB level (-1 substage). Overall, the concrete-IIA subjects showed an average gain of 1.5 substages, the concrete-IIB subjects

gained an average of 0.69 substages, and the formal-IIIA subjects gained an average of 0.33 substages.

Discussion

The results shown in Table 1 demonstrate that the exploration-invention-discovery sequence of instruction was effective in enabling subjects to perform at a higher level on the trained task. The answer to the first question posed at the outset of this investigation is, therefore, a qualified yes. Training can increase subject performance on a task using materials similar to those used in the training sessions. However, the fact that the experimental group did not outperform the control group on the two tasks designed to measure transfer of training suggests that the superior performance on the trained task was probably not due to increased understanding or growth of intellectual ability but rather was simply a matter of rote learning. This tends to support Piaget's position that a direct attempt to teach students to control variables is of little value.

The finding that students classified as early formal operational thinkers (formal operational-IIIA) on the Longeot test showed less improvement due to training than the concrete operational students (concrete operational-IIA and concrete operational-IIB) was somewhat unexpected. In fact the opposite result was expected since Piagetian theory predicts that training will be effective only for subjects at a transitional level--in this instance late concrete operational or early formal operational students. The answer to the second question posed at the outset is, therefore, no. Students who were classified as early formal operational thinkers did not appear to benefit more from training than concrete

operational students in this specific instance. This may simply be a further indication that the increased performance on the trained task was largely due to rote learning and not any general increase in understanding. It should be pointed out that a ceiling effect may also have influenced this result.

Why was the training not more successful? Piaget states that four factors are necessary for intellectual development, (1) maturation, (2) concrete experience, (3) social transmission, and (4) self-regulation (equilibration). Since all subjects in this study were over 14 years of age, it seems highly unlikely that a lack of physical maturation was the reason for the relative ineffectiveness of the training. The training procedures certainly contained concrete materials and all of the subjects were actively engaged in physically manipulating those materials. Also social transmission was a component incorporated into the training phase. The concepts of variables, controlled variables, and controlled experiment were all introduced, discussed, and rediscussed at length. This was done not only with groups of students but with every individual student as well. Students worked in teams which encouraged student to student interaction. If the Piagetian model is to be accepted, the factor most likely missing from the training sessions was the self-regulation or equilibration factor. A possible reason for the lack of self-regulation by the students was a lack of a sufficient number and variety of experiences which would enable the students to arrive at the desired understanding at their own rates.

What follows is a hypothetical model of how the self-regulation process might operate in the context of those training sessions to facilitate understanding

of the desired concepts if more experiences had been provided. Before a person is going to change his way of approaching and solving problems (i.e., his cognitive structures and his mode of operation), his present way of thinking and his behaviors must be found ineffective. A situation must arise which provokes him to reanalyze his thinking. To borrow Piaget's term, he must find himself in a state of disequilibrium. Once this has occurred the factor of self-regulation begins to operate. What presumably occurs is this. The student approaches the pendulum problem as an undifferentiated whole. He does not realize what the variables which might affect the period of the pendulum are, or even what the words variable or period refer to. The primary task then is to engage in concrete experience with the materials to find out what actual physical entities are involved. Once the dependent variable - the period of the pendulum, and the independent variables - weight of bob, length of string, and angle of drop (let us exclude the variable of push to simplify the argument) have been clearly differentiated in the subject's mind, he can begin to attempt to answer the question, what variable or variables affect the period? If he does not understand the idea "all other things being equal," arriving at an unambiguous answer to that question is not possible and disequilibrium results. Social transmission, however, can now effectively enter the process. By being told directly (by the teacher or students) or indirectly (by watching other students succeed in obtaining unambiguous results) that a method for obtaining an unambiguous answer exists, the subject begins to analyze the situation in an attempt to develop understanding and reestablish equilibrium. The basic process by which this understanding

is achieved we hypothesize is one of reinforcement and abstraction. In the pendulum problem the combinations of variables which can be manipulated to produce a change in the period are as follows:

1. $\Delta w + \Delta l + \Delta a = \Delta p$
2. $\Delta w + \Delta l + \overline{\Delta} a = \Delta p$
3. $\overline{\Delta} w + \Delta l + \Delta a = \Delta p$
4. $\overline{\Delta} w + \Delta l + \overline{\Delta} a = \Delta p$

w = weight of bob, l = length of string, a = angle of drop, p = period, Δ = change, and $\overline{\Delta}$ = no change.

Of the above combinations of variables, only number four leads to an unambiguous test. The realization of this by the subject, however, we believe does not constitute sufficient understanding of the concept of "all other things being equal" to serve as a guide for behavior, i.e., to enable the subject to set up and carry out controlled experiments. Prior to acquisition of this understanding, the basic pattern "all other things being equal" must be abstracted from the specific content, i.e., the specific variables of weight, length, angle, and period. Before the pattern can be separated from the content, different content which contains the same pattern must be provided. Given the new content, the subject again isolates and manipulates variables in an attempt to determine causal relationships. In those new situations the variables will change, the relationships between variables will change; however, one thing will remain the same. That one thing is that the unambiguous test is made when all variables but one are

held constant. Once the subject has abstracted this pattern from the variety of concrete situations he will have developed the desired understanding. He will be able to deal with the form of the problem rather than its specific content. The number of different concrete experiences which are required prior to acquisition of the desired abstraction is presumed to vary among individuals.

This model then would attribute the lack of transfer on the posttests to a lack of a sufficient variety of experiences which would enable students to fully come to grips with and to think through the problems and to self-regulate during the training sessions. A prediction which follows is that if more experiences similar to those provided in the training phase occurred during the course of a few months or perhaps an entire semester and if students were encouraged to think through the problems at their own rates, then they would not only perform at an increased level on the trained tasks but this training would transfer to tasks requiring the controlling of variables with novel materials. If this transfer of training is obtained, it would be of theoretical as well as practical interest to determine whether or not the training is also generalizable to problems such as the equilibrium task which Piaget claims also requires formal thought but of a different nature.

Implications for Teaching

The extraordinary aspect of this research in terms of science teaching was the finding that the training was not successful in promoting appreciable understanding of the controlling variables concept. On the surface it would seem that just walking in and explaining to high school students what a controlled

TABLE 1

COMPARISON OF EXPERIMENTAL AND CONTROL GROUP MEAN POSTTEST SCORES

Task	Experimental		Control		T
	Mean	S.D.	Mean	S.D.	
Exclusion	3.12	.93	2.53	.80	*2.74
Separation	2.57	.61	2.56	.62	.09
Equlibrium	2.57	.61	2.69	.64	-.72

*p < .01

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experiment is and describing how to perform one would be sufficient. After all, these students were not elementary school students who had never heard of or done experiments before. They were high school sophomores, juniors, and seniors who had talked about and performed experiments many times.

The finding that understanding of such a fundamental concept as controlling variables is, first of all lacking, and second, not easily corrected, would indeed be unexpected by most science teachers. This statement is not to suggest that the classes in which this study was conducted were selected to be in any way representative of all high school biology classes. Strictly speaking, generalization of these results can be made no further than to the classes from which the subjects were selected. The subjects, however, performed at about the same level of intellectual ability as students of about the same ages from other locations.[4-8]

On the other hand, the possibility exists that the training procedures were simply not appropriate and/or poorly conducted and this was the reason for the lack of success of the experimental group on the posttests. Although this must remain as a possibility, the weight of evidence from similar experiments with Piagetian concepts suggests that this need not be the case. Recall that, as mentioned earlier, the training of specific Piagetian concepts has been successful; however, transfer of that training is seldom obtained. This is precisely the result obtained here.

We believe that the self-regulation and abstraction model described previously requires a variety of concrete experiences and sufficient time to enable

the student to resolve by himself the problem under consideration. It is precisely these two factors which we often find lacking in secondary schools. Teachers frequently ask for immediate understanding and if they do not get it they think that the child has failed or that they have failed. This premature demand for understanding, desire to "cover" material, and fear of loose ends may be a critical factor which encourages rote learning, discourages the process of self-regulation, prohibits the acquisition of abstractions, and thereby limits the growth of formal thought.

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